CONTROL OF SMUTS OF WHEAT AND OATS WITH SPECIAL REFERENCE TO DUST TREATMENTS

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CONTROL OF SMUTS OF WHEAT AND OATS WITH SPECIAL REFERENCE TO DUST TREATMENTS

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Much attention has been given by plant pathologists during the past thirty years to the control of the smuts of wheat and oats. Altho control measures, modified from time to time in form and practice, have been advanced for more than thirty-five years for the control of the smuts, they still continue to exact a yearly toll far in excess of what they should from these cereal crops of Ohio and of other states. This situation is not merely inconsistent with good husbandry, but seriously detracts from a full realization of the benefits to be derived from the use of the most efficient soil fertility practices, varietal selections, and approved cultural methods.

BUNT OR STINKING SMUT OF WHEAT

Economic importance.—Losses vary greatly from season to season. This is true of all types of plant diseases. During some years only a trace of the disease may be found, while the following year infestations ranging from 1 to 30 and even 50 percent may occur. It is usually safe to assume that if any stinking smut whatever is present in the crop of one season, there will be a much higher percentage in the crop of the following year provided no form of seed treatment is employed. On the other hand, it is sometimes noted that there is a lower percentage of smut in the crop than in that of the previous year from which the seed was taken. Estimated losses for the years 1918-1923, inclusive, are indicated in Table 1.

The losses indicated are conservative and undoubtedly are much too low. It is difficult to correlate percent of smut present with loss in yield.

TABLE 1.—ESTIMATED LOSS IN OHIO DUE TO BUNT, 1918-1923

Year	Loss	
	Percent	*Bushels*
1918	.9	395,000
1919	2.5	1,851,000
1920	.5	151,000
1921	.1	35,000
1922	trace	+
1923	.1	50,000

Reduction in yield is not the only form of loss occasioned by this disease. Grain carrying even a low percentage of smut cannot be marketed under the better government grades. It does not measure up to the standards for certified seed. Millers discriminate against wheat bearing any considerable degree of smut, because extra time and expense are required in the cleaning, washing, and scouring of smutted grain before it is fit for milling. In any case, badly smutted wheat brings a lower market price than the smut-free wheat. Mills which are not equipped to provide the necessary cleaning process previous to milling, reject smutted grain altogether.

Cause of the disease.—Stinking smut or bunt of wheat is a fungous disease. The parasite takes its origin each year from the fine, brown to black powder which is found when the smutted grains or smut balls are broken open, Figure 1. This powder is made up of the spores or "seed" of the fungus. In this form the organism is able to survive the interval between harvest and planting of the new crop in the fall. The individual spores are microscopic in size, so small in fact that it has been estimated that a single smut ball may contain two to five millions of them. Entire smut balls, or fragments of them, may be readily detected in the threshed grain, Figure 2. In severe cases, when there is a high percentage of smutted heads in the crop, the grain, during threshing, may become so completely covered with the smut powder or spores, that the normal color may scarcely be perceptible.

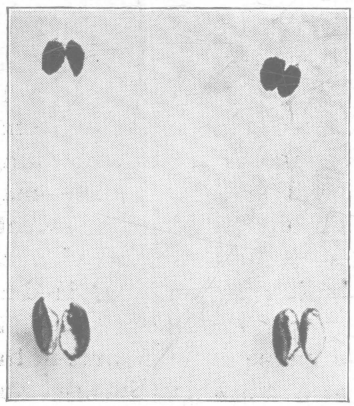

Fig. 1.—Showing the contrast between smut balls (above) and healthy grains (below)

Symptoms of the disease.—Smutted heads are most readily distinguished in the field as the ripening period approaches. The diseased plants remain green longer and stand more erect with the beards or awns projecting out at a greater angle than in normal healthy plants. Frequently a more detailed examination is necessary. When the glumes are torn apart, it is found that they enclose a mass of brownish-black spores encased by a thin, brittle membrane, instead of a normal wheat grain. These spore masses, or false grains, somewhat resemble normal grains in appearance, yet are usually shorter, rounder, and more plump. They are usually referred to as smut balls. This replacement of the normal grain by the growth of the smut fungus constitutes one type of loss occasioned by this disease.

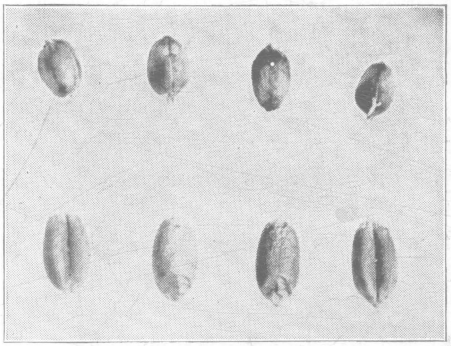

Fig. 2.—Above, smut balls; below, normal grains

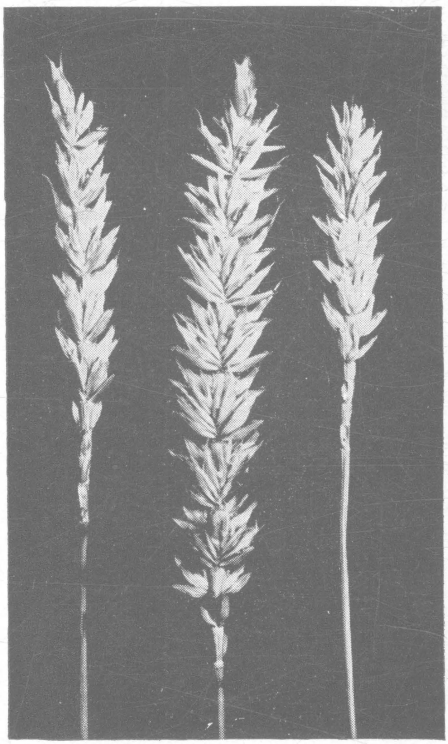

Fig. 3.—Typical diseased heads—stinking smut or bunt of wheat

The broken grains give off a peculiar, fishy odor characteristic of this disease. This is thought to be due to the presence of trimethylamine, an organic compound which is also a constituent of herring brine. This accounts for the fishlike smell always associated with stinking smut. After a time this odor disappears, less readily from grain in the bin but very quickly from standing grain in the field, due to leaching by rain water and to the volatile character of the organic compounds responsible for it. This odor is so pronounced

and characteristic that badly infected fields may be detected at a considerable distance during the ripening period.

Infected plants vary greatly in height. The greater number are usually below the average height for the variety, yet it is a common occurrence to find plants apparently of normal height and vigor with every grain smutted. On the other hand, only a single grain in a head may be replaced by smut. Differentiation has been made of two types of bunt on the basis of height and referred to as the high and low forms, caused by different biologic strains of the fungus. This distinction is, however, without significance for practical purposes, since both strains are amenable to the same methods of control.

Time of infection.—Bunt of wheat is a typical seed-borne disease, the smut spores adhering to the exterior of the seed coat. Infection takes place coincidentally with the germination of the grain. Normally, the period of susceptibility of the seedling is short. Furthermore, the factors which govern infection are not clear. Yet it is a matter of common experience to obtain wide variations in the percentage of smutted plants upon untreated plots from the same seed. In this connection the question arises regarding heavily smutted seed, where every grain carries a heavy coat of spores, why it is that very seldom 100 percent infection occurs. Unknown natural factors, which may either limit or favor infection, are very likely responsible for the wide variations in the amount of smut, and losses sustained from season to season. It seems logical to assume that, if the period of germination of the grain is lengthened due to unfavorable weather conditions, infection would be more likely to occur. Experience, however, does not seem to verify this assumption. In the control tests, discussed later, some of the plots were drilled very late in October. Because of the low temperature, the germination period was greatly extended, yet the amount of smut was considerably less than in other plots which were sowed earlier and germinated normally.

The coleoptile is the region of attack. After the fungus has gained entrance it continues to develop within and at the expense of the wheat plant. A germinating smut spore can survive for only a limited period as a saprophyte, usually not longer than a month. The diseased wheat plants, however, cannot be detected until after the heading stage has been reached when the characteristic symptoms gradually appear as the fungus begins to develop spores, or fruiting bodies, where the grains are normally found in disease-free plants.

How fungus is distributed.—The only means of spread of the wheat-bunt fungus that need be seriously considered are those of a mechanical nature, comprising those operations which are likely to bring together or to mix the smut spores with the grain. The thin, brittle membrane of the smut balls is very easily ruptured when dry, and the spore dust thus liberated becomes mixed with the grain in its passage thru the separator in threshing. In this manner the spread of the disease is rapid to the extent that heavy infections may be anticipated from the use of seed which contained only a moderate percentage of smut the previous year. Custom threshing machines in passing promiscuously from diseased to disease-free crops are commonly responsible for spreading the spores. Likewise, spread may be accomplished thru the agency of containers, such as sacks, measures, drills, bins, etc. Spores upon grain in the bin will remain viable for several years, and for a much longer period in unbroken smut balls. Clouds of spore dust blown from threshing machines may be taken up by air currents and spread over fields which are being prepared for seeding. Spores scattered in this manner over a field have not been found to survive longer than 25 to 30 days. Since it is seldom in Ohio that two successive crops of wheat are grown, soil infection is never likely to become a serious problem in the control of bunt.

Control of the disease.—Effective control methods, based on the idea of sterilizing the outer coat of the grain, thereby killing the smut spores adhering to the surface, have been known for a long time. If care is then taken to guard against reinfection and if the seed is planted in smut-free soil, a disease-free crop is assured. The critical period is while the seed is germinating in the soil. Control measures, such as we are able to devise at the present time, must therefore consist in the application of a fungicide which will kill the spores either before or soon after they germinate or retard their development until the wheat plant is no longer susceptible to attack.

The so-called soaking or sprinkling methods were first employed, using such fungicides as mercuric chloride (corrosive sublimate), formaldehyde, and copper sulphate in solution. All of these gave excellent control of stinking smut. Serious objections, however, have attended recommendations involving any methods requiring wetting and subsequent drying of the grain. Furthermore, many cases of serious injury to germination have been reported following the use of some of the formaldehyde and copper sulphate treatments, caused by delays in planting or drying due to wet weather. Injury to germination has been particularly severe

at times when the dry formaldehyde methods were used. Grains with broken seed coats are particularly liable to be injured by copper sulphate in solution. On the other hand, it must be admitted that there has never been any question regarding the efficiency of any of the wet treatments for smut control, yet the liability of seed injury and the difficulties associated with the drying of the grain have signaled the need for other forms of treatment that would be effective and at the same time obviate the possibility of injury to germination.

The various dust forms of seed treatment which have been under investigation for the past three years offer decided advantages over the wet methods. In all of our tests up to this time there has been no evidence of impairment to the germination of the grain. The excellent results obtained from the use of finely powdered copper compounds, particularly copper carbonate and copper sulphate, reported by Darnell, Smith, and Ross, of Australia, in 1918, have resulted in a very marked advance in the interest now manifested in the treatment of cereal grains for the control of seed-borne diseases. Powdered copper carbonate has gained widest acceptance, being now considered a standard method of treatment.

TABLE 2.—CONTROL OF STINKING SMUT OF WINTER WHEAT, 1922-23

Treatment	Amount per bushel	Smutted	Remarks
	Ounces	*Percent*	
Untreated plots, average of 6		21.0	
Corona copper carb	3	0.5	
Corona copper carb	2	0.8	
Copper carbonate pure	3	0.19	
Copper carbonate pure	2	0.3	
Seed-O-San*	as recommended	1.0	
Chlorophol*	as recommended	3.0	
Formaldehyde (1—320)		0.0	Sprinkling method
Formaldehyde (1—10)			Very serious injury to germination
Copper sulphate powdered (not anhydrous)	3	0.2	
Copper sulphate	2	0.5	
Nickel carbonate	3	1.0	

*This compound is no longer available under this trade name.

The reliability of the copper and nickel compounds in the dust form is strongly manifest in this series of treatments given in Table 2. While there is indication that one is less likely to obtain complete control of smut from the use of the dusts than from formaldehyde, it is evident that commercial control was obtained in all cases. Any form of treatment which reduces the smut to less than 1 percent is satisfactory from the standpoint of disease control and market requirements. From the results presented in Tables 2 and

3 it appears that other forms of dust treatment may also be used to advantage. One need not be restricted to the use of copper carbonate alone. Various other copper or nickel compounds have given virtually as good results as the carbonate.

TABLE 3.—CONTROL OF STINKING SMUT OF WINTER WHEAT, 1924-25

	Treatment	Amount per bushel	Smut
		Ounces	*Percent*
1	Average 10 untreated plots		29.0
2	Corona copper carbonate	2	1.5
3	Same	3	0.5
4	Copper carbonate pure	2	trace*
5	Same	3	0.5
6	Nickel carbonate (acid)	2	1.0
7	Copper sulphate powdered (not anhydrous)	2	trace
8	Same	3	trace
9	Nickel silicate	2	trace
10	Copper stearate	½	0.5
11	Same	1	0.5
12	Same	2	trace
13	Nickel acetate	2	0.0
14	Nickel carbonate (basic)	3	trace
15	Bordeaux mixture dry (11 percent copper)	3	trace
16	Copper acetate	2	trace
17	Same	3	trace
18	Du Pont Dust No. 12	2	trace
19	Du Pont Dust No. 16	2	trace
20	Nickel chloride (anhydrous)	2	trace
21	Same	3	0.6

*Trace indicates less than half of one percent

One would expect more immediate and better results from the use of the sulphates of copper or nickel because these are readily soluble in water, whereas the carbonates are not. The acetates of both metals have never failed to give good results. These, like the sulphates, are readily soluble in water. There has never been any indication of impairment of germination of the seed where any of the soluble salts were used as dusts, altho this has been one of the chief objections to their use in solution. The limited amount of powder adhering to the grain being further reduced in strength due to absorption by the soil as the salt gradually becomes dissolved renders the possibility of seed injury very slight. The introduction of such insoluble compounds as copper and nickel carbonate advances a new idea in the disinfection of grain—namely, the use of an insoluble salt instead of one which would readily dissolve, thus more completely obviating the possibility of seed injury.

The physical properties of the dust are very important. The smaller the particles, the more quickly and thoroly the treatment can be made and the smaller the quantity of powder required. One-half an ounce of copper stearate gave as good covering of the grain and control of smut as three ounces of copper carbonate. Either

form of the carbonate of copper provided better covering than the sulphate when used in equal quantities. It would appear from our experience that a more complete covering of the grain is necessary when a relatively insoluble salt is used than a readily soluble one. In all of the tests included in this report the grain was planted in soil slightly acid.

LOOSE SMUT OF WHEAT

It would be difficult to say whether stinking smut or loose smut causes greater loss to the wheat crop of Ohio over a five- or ten-year period. There is a tendency for losses due to loose smut to be somewhat more uniform and less sporadic from year to year than in the case of stinking smut. Reductions in yield caused by bunt are subject to wide variations, as shown in Table 1. Whereas, the percentage of loose smut for the State as a whole is seldom less than 1.5 percent or more than 2 or 3 percent for any one season, altho individual losses of 10 to 20 percent are not uncommon. The estimated losses in the wheat crop due to loose smut over the six-year period, 1918-1923, inclusive, are presented in Table 4.

TABLE 4.—ESTIMATED LOSSES DUE TO LOOSE SMUT OF WHEAT, 1918-1923

Year	Smut	Estimated loss
	Percent	*Bushels*
1918	1.9	843,000
1919	2.0	1,481,000
1920	2.0	604,000
1921	1.0	325,000
1922	2.0	1,004,000
1923	1.5	756,000

The loose smut of wheat is much more conspicuous and readily recognized than bunt, or stinking smut. As the heads appear the carbon-black color, Figure 4, of the spikes of diseased plants presents a sharp contrast to the normal heads. The black powder, comprising the spores of the fungus, is so very readily dispersed when dry that by harvest time it has nearly all disappeared leaving the rachis bare.

Time of infection.—This type of smut is a seed-borne disease of an entirely different nature from bunt, or stinking smut. Instead of the spores being carried on the outside of the grain and thus gaining entrance into the plant at time of germination, infection is accomplished during the blossoming period, and the fungus establishes itself in the embryo of the grain. In this position it is protected from the toxic effect of fungicides ordinarily used for seed sterilization.

Because of the difficulty of reaching the parasite on the interior of the grain, the hot-water method of treating the seed is the only means of control yet available. The selection of strains resistant to loose smut may give promise; but so many factors, besides its relative resistance or susceptibility to smut, are to be considered in estimating the value of a selection of wheat, that such a course of investigation is not likely to produce desirable results.

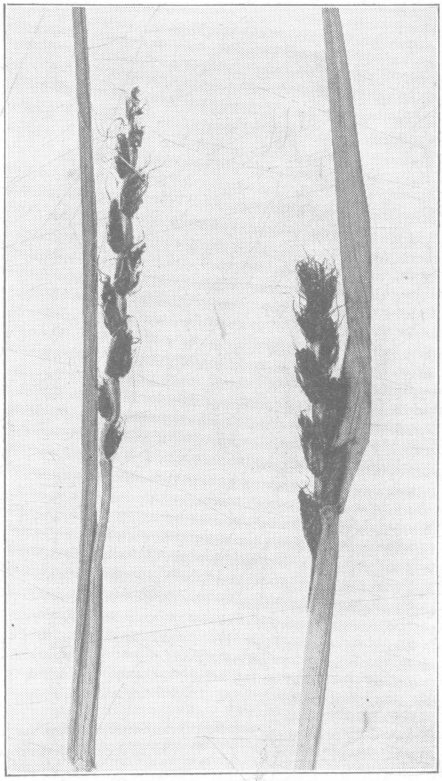

Fig. 4.—Loose smut of wheat

The modified hot water method.—The seed to be treated is first presoaked in water at room temperature for four to six hours. Treatment may be conveniently made in bags containing one or two pecks of grain. With small lots it is easier to maintain the required temperature, thus making the treatment more thoroly and readily accomplished.

For the main part of the treatment, two tubs or vats are necessary. In one the temperature of the water should be about 120° F., while in the other the temperature must not be allowed to vary more than a degree above or below 129° F. The ease with which the desired degree can be maintained depends, to a considerable extent, upon the volume of water used and the method of heating.

In practice, the wheat, presoaked for at least four hours, is removed from the cold bath and allowed to drain for a moment, then plunged into vat No. 1, kept at about 120° F., until the grain has been raised to this temperature. This usually requires one to two minutes. Then it is immediately immersed in vat No. 2, for 10 minutes, at 129° F. If the temperature of the water rises or falls the time of treatment should be shortened or lengthened as the case may be. Immediately after treatment, the grain is spread to dry.

It is important that all the seed be uniformly heated. Consequently, it is a distinct advantage to treat only small quantities at one time. If treatment is made in bags, the grain must be agitated thoroly until there is a uniform temperature thruout.

SMUTS OF OATS

Cause and importance.—Two species of smut fungi are recognized to be parasitic upon oats in Ohio—namely, *Ustilago avenae*, the cause of loose smut, Figure 5, and *Ustilago levis*, responsible for

Fig. 5.—Smuts of oats: Covered smut left, loose smut right. Note striations on leaves at right

covered smut, Figure 6. From the standpoint of control this distinction of species does not need to be considered; for both forms of smut are seed-borne, subject to the same agencies of distribution, and both can be eradicated by the same methods of seed treatment. A greater percentage of the oat crop is destroyed by the smuts than

by any other disease. Losses, however, are not equally severe from year to year, yet are usually of serious economic importance whenever infected seed is planted without treatment. The estimated losses in Ohio for 1918 to 1923, inclusive, are presented in Table 5.

TABLE 5.—ESTIMATED LOSSES DUE TO OAT SMUT
1918-1923

	Loss	
	Percent	*Bushels*
1918	7.2	6,145,000
1919	4.0	2,305,000
1920	2.0	1,486,000
1921	1.5	589,000
1922	trace	.....
1923	trace	.....

Severe reductions in yield of cereal crops due to disease appear to be somewhat periodic in occurrence. In 1918 losses due to smut were particularly severe; in the years following much lower percentages were quoted. Natural causes may in part be responsible for marked variations in loss, but they cannot be depended upon to eliminate the disease. Following years of heavy smut infection more attention is given to seed treatment and to securing of grain for seed purposes which is free from smut. A few years of relapse and neglect of seed treatment pave the way for heavy smut infection which is sure to recur sooner or later. The real value of seed treatment is most fully appreciated during years of abundant smut which results in reduced yields and often is coincident with high market prices.

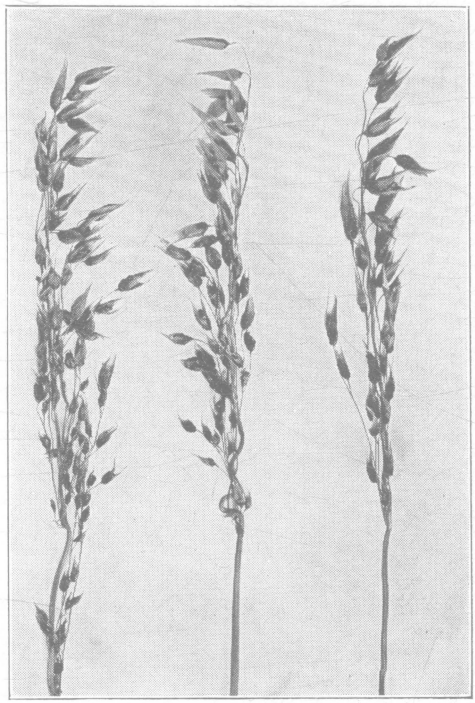

Fig. 6.—Covered smut of oats

Symptoms.—No difficulty is presented in the recognition of either form of oat smut. Diseased plants cannot be detected by gross

inspection, however, before the heading stage is reached. The blackened, smutted heads appear about the same time or a little later than the normal panicles. Upon examination it is found that the grain and enveloping portion are completely invaded by the fungus, Figure 5. Sometimes, under very favorable conditions, the leaves as well as the panicles are smutted, Figure 5, right.

Time of infection.—As in the case of bunt of wheat, infection of the oat plant occurs during the seedling stage of the oat plant. It is thought that this period is comparatively short. Spores adhering to the seed coat of the grain germinate at the same time as the seed, effect an entrance into the young seedling, and continue to develop in parasitic relationship, which is terminated only by the maturity and death of the host. There is no evidence that we need to concern ourselves further than the seed-borne spores as a source of infection. Apparently the smut fungus is unable to survive as a saprophyte under field conditions for any considerable period, altho the spores will remain viable upon grain in the bin for at least four years.

Distribution of the spores is accomplished thru the agency of the wind while the grain is in the field and in the harvesting and threshing operations. The dispersal of the spores is likely to be more complete with oat smut than with wheat due to the character of the fungus, the spores being more readily dislodged because they are very loosely held in place. An infection of 1 or 2 percent in a crop may well result in a much greater amount of smut, even 10 or 20 percent, the following year.

Control of the disease.—A number of methods have been devised from time to time for the control of this disease. These are satisfactory when considered from the standpoint of control alone. All methods, however, which require wetting or soaking of the grain, have been open to objection and for this reason have not gained as universal favor as desired. Likewise, the so-called dry methods in which formaldehyde is employed and only a small amount of liquid incorporated with the grain, thus obviating the tedious drying process required with the sprinkling or soaking methods, have not come into as general use as they merit, due to the possibility of seed injury. Because of the objections so frequently advanced against the use of methods currently recommended for the control of oat smut, and because of the fact that none of these methods seemed likely to gain as wide acceptance as desired, a project was started in 1922 for the purpose of finding a fungicide which would be available for use in the dust form.

For two years only single compounds were employed, comprising chiefly various salts of copper, nickel, and mercury. No single salt was found to possess adequate, available fungicidal efficiency to give the desired degree of control. It was then decided to try a combination of copper and nickel carbonates, sulphates, and acetates, respectively, with the bichloride of mercury. Results of the first trial are given in Table 6. In these tests two parts by weight of the mercury salt were combined with one part of the copper or nickel salt, respectively. In the preliminary trial the pulverizing and mixing was done by hand with the use of a mortar and pestle. The mixtures were used at the rate of 3 ounces for each bushel of grain. All tests were made in one-hundredth acre plots, the grain being drilled as in ordinary farm practice. In determining the amount of smut six representative samples of 150 to 200 straws were cut from each plat and counted.

TABLE 6.—RESULTS OF SEED TREATMENT FOR CONTROL OF OAT SMUT IN 1924

	Treatment	Smut	Stand on basis of check	Disease free straws in terms of stand	Gain or loss of disease free straws over check
		Pct.	*Pct.*	*Pct.*	*Pct.*
1	Check, no treatment	32.0	100.0	68.0	−32.0
2	Formaldehyde, sprinkling method	0	87.5	87.5	+19.5
3	Formaldehyde, diluted (1—1) with water	0.01	97.2	96.2	+28.2
4	Formaldehyde diluted (1—10) with water	0.007	94.2	93.2	+25.2
5	Copper carbonate powder	4.6	105.3	100.4	+32.4
6	Copper carbonate plus mercuric chloride	0.05	101.5	101.3	+33.3
7	Copper sulphate (not anhydrous)	11.4	102.0	90.3	+22.3
8	Copper sulphate plus mercuric chloride	0.7	112.0	111.9	+43.9
9	Nickel carbonate	3.6	100.7	97.1	+29.1
10	Nickel carbonate plus mercuric chloride	0.5	111.0	110.4	+42.4
11	Copper acetate	8.0	107.0	98.4	+30.4
12	Copper acetate plus mercuric chloride	0.5	116.0	115.6	+47.6

It was hoped in this series of tests that a preparation could be found which would not only be satisfactory as a fungicide, but which would also stimulate the germination, if possible, or at least not impair it. The data presented in the table indicate that in the case of the copper and nickel compounds combined with mercuric chloride there is considerable evidence of stimulation in the germination of the grain. This is not so strongly evident in the data from the plots treated with formaldehyde. Neither is it apparent in the plots treated with the single copper or nickel compounds.

In the tests of the following season an attempt was made to determine to what extent the original mixtures which had satisfactorily controlled smut in 1924, could be adulterated by the addition of a supposedly inert kaolin filler and still retain adequate fungicidal value. Accordingly, mixtures were prepared by the Gras-

selli Chemical Co., Cleveland, Ohio, following the proportions indicated in Table 7. It was hoped that the mixtures would be considerably reduced in cost by the addition of a cheap adulterant. It was also thought desirable to determine to what extent corrosive sublimate alone could be adulterated and still retain its value as a fungicide. For this purpose hydrated lime was used. The possibility of a reaction between the lime and the mercury salt was not

TABLE 7.—SMUT CONTROL AND YIELDS RESULTING FROM DIFFERENT TREATMENTS UPON INFECTED SEED OATS. ALL TREATMENTS USED AT THE RATE OF 3 OUNCES PER BUSHEL
1925

	Treatments used	Smut	Yield per acre
		Percent	*Bushels*
1	Average of 10 untreated plots	25	29.3
2	Copper carbonate 1 part, Mercuric chloride 2 parts	3	41.3
3	Copper carbonate 2 parts, Mercuric chloride 1 part	7	32.0
4	Copper carbonate 1 part, Mercuric chloride 2 parts, 1 part, filler 1 part	15	28.8
5	Copper carbonate 2 parts, Mercuric chloride 1 part, 1 part, filler 1 part	19	37.6
6	Copper sulphate 1 part, Mercuric chloride 2 parts	3	41.1
7	Copper sulphate 2 parts, Mercuric chloride 1 part	5	40.0
8	Copper sulphate 1 part, Mercuric chloride 2 parts, 1 part, filler 1 part	13	37.8
9	Copper sulphate 2 parts, Mercuric chloride 1 part, 1 part, filler 1 part	12	36.6
10	Nickel carbonate 1 part, Mercuric chloride 2 parts	4	42.0
11	Nickel carbonate 2 parts, Mercuric chloride 1 part	3	41.3
12	Nickel carbonate 1 part, Mercuric chloride 2 parts, 1 part, filler 1 part	10	44.6
13	Nickel carbonate 2 parts, Mercuric chloride 1 part, 1 part, filler 1 part	6	41.3
14	Copper acetate 1 part, Mercuric chloride 2 parts	1	37.4
15	Copper acetate 2 parts, Mercuric chloride 1 part	9	41.3
16	Copper acetate 1 part, Mercuric chloride 2 parts, 1 part, filler 1 part	19	36.6
17	Copper acetate 2 parts, Mercuric chloride 1 part, 1 part, filler 1 part	19	36.6
18	Copper stearate	22	34.6
19	Copper stearate 1 part, Mercuric chloride 2 parts	11	38.2
20	Copper stearate 2 parts, Mercuric chloride 1 part	18	36.9
21	Copper stearate 1 part, Mercuric chloride 2 parts, 1 part, filler 1 part	20	33.2
22	Copper stearate 2 parts, Mercuric chloride 1 part, 1 part, filler 1 part.	27	30.3
23	Mercuric chloride 1 part, filler 1 part	29	32.2
24	Mercuric chloride 1 part, filler 2 parts	27	28.5
25	Mercuric chloride 1 part, filler 3 parts	32	31.8
26	Mercuric chloride 1 part, filler 4 parts	39	30.4
27	Mercuric chloride 1 part, filler 5 parts	29	34.0
28	Copper carbonate 4 parts, Mercuric chloride 1 part	11	38.2
29	Copper sulphate 5 parts, Mercuric chloride 1 part, 1 part, filler 1 part	29	34.0
30	Copper carbonate 5 parts, Mercuric chloride 1 part, 1 part, filler 1 part	13	41.5
31	Bayer dust	25	33.2
32	Nickel chloride (anhydrous)	2	37.7
33	Formaldehyde (dry method)	trace	41.0
34	Formaldehyde (sprinkling method)	0.6	42.9

appreciated until it was too late to redeem the experiment. The corrosive sublimate and hydrated lime mixture did not control smut in any case, but rather appeared in several of the series to stimulate its development. It is very probable that a reaction took place between the two compounds as they entered into solution in the soil resulting in the formation of oxide of mercury and calcium chloride. In this way the fungicidal value of the mercuric chloride was entirely destroyed.

It was further determined by this series of experiments that all variations from the proportions of the original formulas resulted in a marked reduction in the efficiency of the mixtures as fungicides for the control of oat smut. The copper and mercury salts combined in the proportion of one to two are superior to the same salts mixed in reverse proportion. The addition of a kaolin filler to each of the two mixtures reduced the fungicidal value of the mixtures to such an extent that even commercial control of the smut was not realized, whereas the original mixtures carrying one part of copper to two parts of the mercury salt gave satisfactory control in all instances.

TABLE 8.—RESULT OF FIELD TEST ON GEORGE REED FARM NEAR SHREVE, OHIO, 1925

	Treatment	Smut
		Percent
1	Copper carbonate 1 part, Mercuric chloride 2 parts	2.0
2	Copper sulphate 1 part, Mercuric chloride 2 parts	0.3
3	Copper acetate 1 part, Mercuric chloride 2 parts	0.2
4	Check, not treated	18.0

In addition to the experiments which were conducted in one-hundredth acre plots, opportunity was afforded to conduct a field test comprising about twenty acres on the farm of George Reed near Shreve, Ohio. Three of the most efficient mixtures, as indicated in the tests of 1924, were used in this work at the rate of 3 ounces of powder per bushel of grain. The results of smut control, given in Table 8, were found to be in close agreement with the plot work.

METHOD OF APPLICATION OF FUNGICIDES

General.—A limited experience in the use of fungicides either in the liquid or dust form is sufficient to convince one that much depends upon the method of application. This is important, not

only from the standpoint of thoroness of application, thereby insuring complete disease control, but also from the standpoint of ease and convenience of treatment. All fungicides are poisons, and vary according to the nature of the compound in degree of toxicity. Formaldehyde, a gas in solution, is often found to have an irritating effect upon the membrane of the throat and nasal passages. This effect is also experienced in the use of dusts. The copper dusts, particularly copper carbonate and copper sulphate, have an irritating effect, which appears to be somewhat more marked when they are combined with corrosive sublimate. It is, however, of a transient nature and need not serve as a deterrent to the use of any fungicides in the dust form.

How to use dusts.—The most efficient and convenient method for treating grain with dusts is in some form of closed container. The small rotating churn, Figure 7, was used in the greater part of the work included in this report. A half bushel of grain could be treated at one time, requiring about two minutes for thoro coating of the seed. In Figure 8 is shown another type of machine adapted for seed treatment at the Ohio Agricultural Experiment Station. The capacity of this power machine is 6 to 10 bushels of grain, and treatment can be made within five to seven minutes.

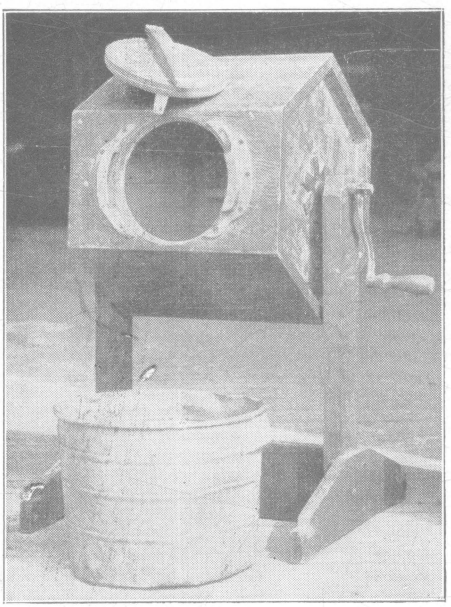

Fig. 7.—This type of 10-gallon rotary churn is very satisfactory for treating grain with dust

In an earlier report* it was suggested that treatment be made by shoveling the grain spread upon a floor until the powder was thoroly mixed with it. While effective results can be obtained from this method it will be found, on the whole, very unsatisfactory, because much of the fungicide will be lost and the dust arising unpleasant to inhale. Later experience has demonstrated the value of using a closed container. Some have used a cement mixer and

*Ohio Agr. Exp. Sta. Monthly Bul., Jan.-Feb., 1924.

have found it quite suitable. It has one disadvantage in not being entirely closed, thus allowing considerable dust to escape during the mixing. A barrel can very easily be adapted for this work. Several strips should be fastened on the inside to catch the grain and allow it to fall over and thoroly mix as the container is being rotated.

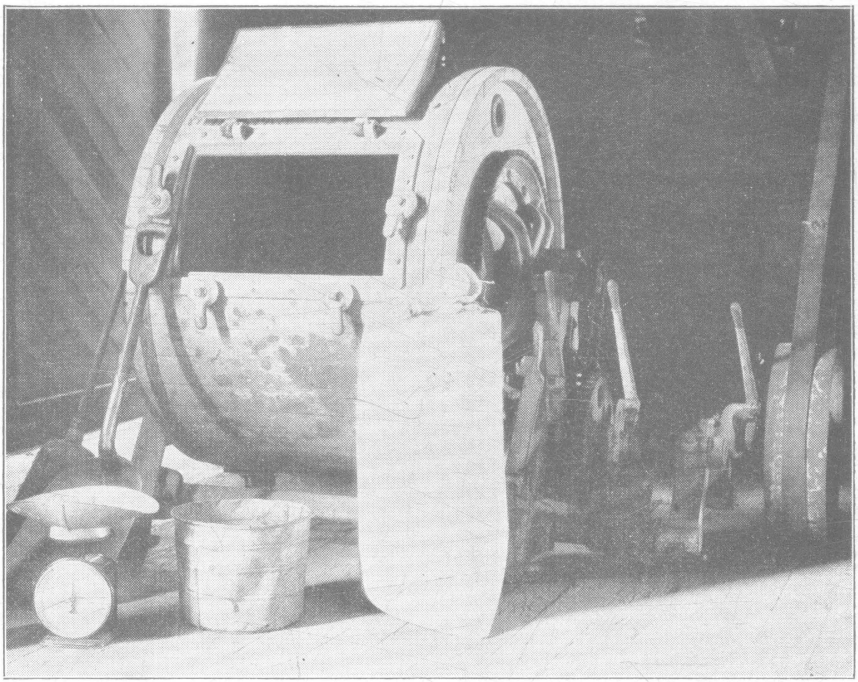

Fig. 8.—Large quantities of grain can be quickly treated with the use of a power machine

How much powder to use.—We have not seen fit to change our former recommendation of 3 ounces (3 heaping tablespoonfuls) of powder for each bushel of grain treated. Within reasonable limits the cost of the dust is a minor matter in the control of grain smuts. Two ounces may be found to be sufficient if the seed carries only a small percentage of smut and if longer time be given to the treatment. In our own tests we have always secured better smut control from the use of 3 ounces of dust than from 2 ounces.

OTHER TREATMENTS FOR SMUT CONTROL

It cannot be said that the dust methods of seed treatment have entirely superseded the sprinkling, soaking, or so-called dry formaldehyde practices. For this reason salient features of the different

wet methods and a brief discussion of their relative merits are included. All of the treatments given may be used for the control of the stinking smut or bunt of wheat and for the smuts of oats. None, however, have been shown to possess any merit for the control of loose smut of wheat.

Formaldehyde

Sprinkling method.—Spread the grain upon a clean floor or canvas. As it is being shoveled over, sprinkle with a solution of 1 pint of 40-percent formaldehyde to 40 gallons of water. About three-fourths of a gallon of this solution will be required for each bushel of grain. Every kernel should be moistened. After treatment allow piles to remain undisturbed for two or three hours, then spread to dry. This formalin solution is also available for the disinfection of bags, bins, and machinery. Treated grain should be handled only in disinfected containers.

Spraying or dry treatment.—Spray the grain which is being shoveled over with a solution of 1 part of 40-percent formaldehyde and 1 part water. A small vapor sprayer is convenient to use for this purpose. About 1 quart of the liquid will be required for each 50 bushels of seed. After the treatment cover with canvas, sacks, or blankets for four or five hours. Best results will be obtained if the seed be planted as soon as possible after treatment. If the grain is held very long after treatment there is likely to be danger of serious injury to germination. Since the formaldehyde vapor acts as an irritant to the mucous membrane of the eyes, nose, and throat, a good circulation of air should be arranged when the treatment is being made, and the vapor sprayer should be held close to the grain.

Modified spraying treatment.—Dilute 1 pint of formalin with 10 gallons of water. This solution may be applied as above with a vapor sprayer, using about one pint of the liquid for each bushel of seed. At this rate one pint of formalin will be sufficient to treat about 80 bushels of grain. After applying the liquid, thoroly mix by shoveling over, then cover for two hours. In the case of oats, all of the moisture is usually taken up by the grain so that it can be sown immediately.

Best results from the use of any of the formaldehyde treatments will be obtained if the grain is planted as soon as possible after the treatment is made. In this way good control of the smut may be secured with a minimum of seed injury.

Copper Sulphate, or Bluestone

The well cleaned seed may be dipped for 10 minutes in a solution of copper sulphate or bluestone. The strength commonly used is 1 pound of copper sulphate to 10 gallons of water. The addition of 1 pound of common salt to the solution has been considered to add to the effectiveness of the copper sulphate solution without increasing the possibility of injury to germination. The grain should next be dipped in a lime solution prepared by adding 1 to 2 pounds of hydrated lime to 10 gallons of water. This reduces the injury to germination by counteracting the action of the copper sulphate. Grains having broken seed coats are more susceptible to injury than normal grains. The bluestone treatment has special merit in that the seed remains coated with a fungicide, thus precluding the possibility of reinfection afterwards.

COMPARISON OF DUSTS AND WET METHODS

Smuts of wheat (excepting loose smut) and oats can be controlled by both forms of treatment. There does not appear to be any possibility of seed injury from the use of the dusts included in this report, while this is one of the outstanding objections to formaldehyde and copper sulphate in solution. Dust treatments can be made quickly at any convenient time and the grain will not require further attention beyond this mere coating with dust. Grain treated with formaldehyde and not used for seeding purposes may be fed to stock, while it would not be safe to feed seed treated with copper sulphate and lime or with any of the dust forms.

It has been repeatedly noted that plots receiving dust treatments, particularly the copper and nickel compounds, show less winter injury than the plots treated with formaldehyde.

The cost of copper carbonate for treating wheat compares favorably with formaldehyde. The slightly higher cost, 1 to 2 cents per bushel, is well compensated by the convenience of treatment. The dust combinations which were found effective against smuts of oats range much higher in cost, 10 to 13 cents per bushel. This is due to the high price of the corrosive sublimate used in the mixture. This, in turn, is compensated by the fact that there does not appear to be any possibility of injury to the seed from the use of the dust treatments.